Executive functions and psycho-behavioural skills in artistic gymnasts: age, developmental stage and sex related differences

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During the talent development (TD) process in sport, cognitive and psycho-behavioural skills are necessary to successfully overcome TD specific challenges. This cross-sectional study explored executive functions (EF) and psycho-behavioural skills (PCDE), in male and female high-level artistic gymnasts between 9 and 26 years old. The first objective was to investigate if an ideal profile would emerge for these gymnasts. In the youngest age group (9-12yo), a general improvement with age for EF was observed, and gymnasts scored higher on imagery use than the quasi-control group. The older age group showed that gymnasts had significantly higher scores on inhibition, imagery use and self-directed control and management than the quasi-control group. The second objective was to conduct a person-centred approach, investigating the individual profiles of a selected group of four high-level gymnasts. The radar charts revealed a relatively similar profile in all four gymnasts and the quasi-control group for the EF components, while there was a pronounced within group and between groups variation for the PCDE profiles. This study showed that inhibition, imagery use and self-directed control and management could be potential performance indicators in gymnastics. The radar charts support the idea that, once an athlete scores above a specific threshold on all variables, there is no necessity for trying to maximise each and every of these skills but rather, it might be better to leave room for individual profile variation. Since individually different profiles were indeed observed, we recommend an athlete-centred approach in all TD phases from a young age onwards.

Keywords: talent development, athlete development, athlete-centred approach, psychometric assessment, sport

Introduction

The talent development (TD) process in sports is dynamic, complex and nonlinear (Abbott et al., 2005; Phillips et al., 2010; Simonton, 2001); a period during which athletes have to overcome and benefit from many challenges (Collins et al., 2016). During all TD stages cognitive skills are necessary to successfully overcome these challenges (Gould et al., 2002; Larsen et al., 2012; MacNamara et al., 2010a; Olszewski-Kubilius et al., 2019; Olszewski-Kubilius et al., 2015). Cognitive skills is a broad term, however, defined as the need to acquire, process, store and act on information from the environment in an adaptive way (Bayne et al., 2019; Shettleworth, 2009). Executive functions (EF) reside under the umbrella term of cognitive skills, and can be defined as a general purpose control mechanism that modulates the operation of various cognitive sub-processes, thereby regulating the dynamics of human cognition (Miyake et al., 2000) . In contrast to the more robust EF, psycho-behavioural skills are a collection of socially, culturally and contextual dependent cognitive skills (e.g., stage of athletic development; Dohme et al., 2017; Henriksen et al., 2010; Larsen et al., 2012; MacNamara et al., 2010b). Psychological skills can be seen as specific, individual skills (e.g., the ability to use coping or imagery skills; Kautz et al., 2014), necessary to assess, regulate and/or enhance psycho-behavioural skills (Dohme et al., 2017). In addition to facilitating the pathway to excellence, both EF and psycho-behavioural skills play an essential role in high-level performance development and performance (Durand-Bush & Salmela, 2002; Orlick & Partington, 1988). Research on EF has highlighted that athletes score higher on some EF components than non-athletes (Jacobson & Matthaeus, 2014; Vestberg et al., 2012), and highly talented athletes tend to outperform amateurs when it comes to inhibition and decision making (Verburgh et al., 2014; Vestberg et al., 2012). However, the importance of EF can differ between sports as performance determinants are not universal for all sports. Externally paced athletes rely on fast and accurate decision-making processes in dynamic environments (Pesce, 2012; Singer et al., 1996; Zoudji et al., 2010), and often score higher on problem-solving tasks (Jacobson & Matthaeus, 2014). In self-paced sports, senior athletes (e.g., gymnasts) generally score higher on inhibition (Jacobson & Matthaeus, 2014) compared to externally sports (e.g., basketball). Self-paced sports, by contrast, are defined as activities where athletes have time to prepare for critical actions or movements and perform at a pace they can control themselves (Singer, 2000, 2002). Key to maximising quality during practice and performing well for these athletes, is the ability to suppress external and internal distractors, which relies on inhibition skills (Singer, 1988).

In addition to the nature of the sport, performance level is also related to psycho-behavioural skills. MacNamara and Collins (2013) showed that although small differences were found in the deployment between individual and team sport athletes, high-level (adolescent) athletes already have better levels of psycho-behavioural skills compared to sub-elite or drop-out athletes. These skills are labelled as 'psychological characteristics of developing excellence' (PCDE) and are skills young athletes specifically needed during their TD process, to face, overcome or even benefit from TD challenges (MacNamara & Collins, 2013). PCDE are a combination of both crucial state-deployed skills ("the ability to ... when ...") and trait characteristics ("the tendency to ...").. can be adaptive for the TD pathway, such as the use of imagery, the ability to cope with pressure, or the support from significant others (Hill et al., 2019; MacNamara & Collins, 2011). In contrast, some psychological characteristics are either mal-adaptive (e.g., clinical indicators), or can have a dual effect (e.g., perfectionism) on pathway success (Hill et al., 2019; Hill et al., 2016). To help athletes benefit maximally from practice and performance opportunities, athletes should develop PCDE from a young age onwards (Blijlevens et al., 2018). Nevertheless, both EF and PCDE research in sports is currently focused on (senior) adult athletes. Consequently, more insight in the development of EF and PCDE in the younger athletic group could potentially improve performance and/or facilitate the TD pathway of gymnasts.

Inter-individual differences from the ‘optimal profile’ may still be observed at senior level, since TD is a non-linear process (Abbott et al., 2005; Phillips et al., 2010; Simonton, 2001). Variation in the ‘optimal profile’, even at the highest level, seems to imply that a minimal threshold in a skill-set must be reached, in order to succeed at the senior high level. However, once this minimal threshold is reached, variation within and between individuals is possible. Most elite high jumpers in Olympic finals for example are characterised by above average height, although there are significant differences in the height range within the elite high jumpers group. Furthermore, research has indicated that psychological skills and their behavioural characteristics are influenced by emotional, cultural and social factors, resulting in an interactive skill-set allowing for variation between as well as within individuals (Dohme et al., 2017; MacNamara & Collins, 2015; Zell et al., 2015). Given these variations that might not be detected at group level but are important for the individual at elite level, there is a growing call to use a more person-centred approach in TD studies (Ivarsson et al., 2015; Roberts et al., 2021). This not only to detect small, yet important, individual differences in the elite athlete profile, but also for practitioners or sport psychologists working with elite athletes. These practitioners need to require more information on how a person-centred approach can be used in TD programs, which will also help them to monitor cognitive skills and tailor individualised programs best fitting the athletes.

Notably, studies investigating EF and psychological characteristics have drawn predominantly on male and/or team sports populations, and less on individual sports (Ivarsson et al., 2015; Larsen et al., 2013; Mills et al., 2014). In studies where EF and psychological characteristics are investigated in individual sports, mostly a female population is used, especially in artistic sports such as gymnastics (Duarte et al., 2015; Martinez et al., 2021; Pineda et al., 2011; Waples, 2003). The general lack of studies in a male population in gymnastics, makes it difficult to hypothesise on possible differences between both sexes. Indeed, in EF research, it is still much debated if sex differences exist (for a review, see Grissom & Reyes, 2019). For the psychological characteristics, sex differences often depend on the developmental stage, type of sport and the specific characteristics that are investigated (Dorn et al., 2006; Kruger et al., 2019; MacNamara & Collins, 2013). From the few studies on the topic, differences between males and females are typically small in magnitude and more support has been given to the 'gender similarities hypothesis' (Zell et al., 2015).

Typically, research examining talent in sports is searching for an optimal profile with key aspects or performance determinants based on group means at senior high-level (Bergkamp et al., 2019; Figueiredo et al., 2009; Pion et al., 2015). EF and PCDE are two performance determinants that could play an important role at an early stage in the TD pathway, especially in an early specialisation sport such as gymnastics (Longo et al., 2016). To illustrate, athletes benefit from using self-directed management skills during practice, from inhibiting distracting cues during competition or from applying imagery use during an injury process, which will in turn facilitate the TD pathway. However, intra-individual variation is not to be neglected as well during TD.

This cross-sectional study explored both EF and PCDE performance in male and female high-level artistic gymnasts from 9 to 26 years old. Firstly, we investigated whether an ideal profile would emerge for these gymnasts by comparing the EF and PCDE of gymnasts with those of a quasi-control group, dependent on age and developmental stage. Based on previous literature, we hypothesise a small advantage for the childhood gymnasts over the quasi-control group on EF, and we expected adolescent gymnasts to outperform a quasi-control group on the inhibition component. We also hypothesised that a general increase with age and developmental stage would occur for both EF and PCDE. Since both male and female gymnasts participated in this study, we also specifically examined sex differences within this ideal profile of EF and PCDE. Lastly, to inspect inter- and intrapersonal differences on EF and PCDE, a person-centred approach with radar plots was used on a selected group of high-level gymnasts. Second to investigating these differences, we also inspected if and how much gymnasts conform to a desired EF and PCDE profile.

Method

Participants.

Gymnasts who were actively competing at the A-level (highest level in Belgian competition) and participated in the Belgian gymnastics TD program were invited to participate in this study and contacted through the Flemish Gymnastics Federation. Each year, the federation organises selection days to recruit talented gymnasts of 9-12 years old for the TD program. Once gymnasts are in the TD program, they are tested multiple times a year, to evaluate if both performance and progress justify continued inclusion in the TD program. Taken together, all Flemish elite gymnasts in the TD program between 9 and 26 years old were included for this study (12.80 ± 3.65 years old; 64 male and 71 female gymnasts), leading to a total of 135 gymnasts.

The gymnasts were divided according to their developmental stage, either aspiring, junior or senior. Aspiring gymnasts train in the regional centres and can only compete nationally. From the moment the gymnasts move to the national centre, they become junior gymnasts. Gymnasts enter the junior stage one year before they can internationally compete, as the minimum age to compete at FIG international competitions is 14 (female) or 15 (male) years old. Senior gymnasts are those gymnasts who are allowed to compete at World Cups and Olympic Games (16 female / 18 male). Minimal age requirements are different for male and female gymnasts, hence, there are small differences in ages in the stages per sex. Table 1 shows an overview of the number of gymnasts participating in this study per sex and stage.

- *Insert Table 1 here* -

Lastly, to have a better indication of the gymnasts' performances in comparison with other athletes, a quasi-control group that matched with the gymnasts was recruited from a pool (N = +/- 1000) of youth athletes in other sports. This group had been tested on earlier occasions using the same test battery as in the current study. Only participants between 9 and 18 years old were selected, who participated in a non-artistic sport for at least 3 hours per week (i.e., participants performing in the following sports were excluded: artistic gymnastics, rhythmic gymnastics, dance, breakdance, ballet, free running, skating, skateboarding and figure skating). This stratified sampling led to 316 participants (207 males, 109 females), from whom eventually 135 were selected to best match the gymnasts according to sex and mean age (64 males, 71 females), Supplementary Material 1 provides information on number of participants per type of sport and sex. Table 2 shows the match of the quasi-control group with the gymnasts.

Informed consent was obtained from each participant. The parents or legal representative for participants younger than 18 years old, gave their informed consent to let their child participate in this study. The Ethics Committee of XXXX approved this study.

- *Insert Table 2 here* -

Instruments.

Cambridge Brain Sciences. For the cognitive assessment, a multidimensional web-based test battery from Cambridge Brain Sciences (CBS) was used. The tests used in the CBS are all computerised versions of well-known and widely used neuropsychological tests to measure EF constructs (see Supplementary Material 2 for a detailed overview for each test and its reliability measure). Seven tasks that included minimal reading or mathematic abilities out of the thirteen CBS-tasks were selected for this study: Spatial Span, Double Trouble, Token Search, Odd One out, Spatial Planning, Monkey Ladder and Sustained Attention to Response tasks (SART). Tests were always assessed in the same order that is stated above online, on a 9.7-inch iPad 2017 (iOS 12.1, Apple Inc, Cupertino, USA).

Psychological Characteristics of Developing Excellence Questionnaire. Participants were asked to fill out the Psychological Characteristics of Developing Excellence – Child version (PCDEQ-C) up until 13 years old and PCDEQ - version 2 (PCDEQ-2) from 13 years onwards on paper (Hill et al., 2019). As the athlete grows older, the set of psycho-social skills and behaviours will increase in number and difficulty, as the demand of the environment will increase in difficulty as well (Blijlevens et al., 2018). The same set of psychological characteristics (PCDE) are used in both groups (see Table 3), all relying on items questioning the adaptive, maladaptive or dual-effect on the athletic TD (Hill et al., 2019).

- *Insert Table 3 here* -

Data analysis.

Originally, 143 gymnasts were recruited for this study. Some of these gymnasts completed the cognitive and psychological assessment two or three years in a row. To avoid methodological issues, data of only the first test session was included. Only for those gymnasts who completed the test battery two times and had transferred to the junior or senior group (N = 26), the last dataset was selected to increase the number of participants in the older age groups. Previous research has indicated that the risk of learning or test effects due to repeated testing is minor if the interval is 12 months or more (Laureys, Middelbos, et al., 2021). Data were also checked for missing values on the cognitive and psychological tool, leading to the deletion of all data of that particular participant. EF data from 8 gymnasts was missing and were thus completely removed, resulting in usable data from 135 gymnasts.

The first part of this study investigated if an ideal gymnastics profile would emerge, and therefore sum scores were made for both the EF and PCDE factors. Previous studies have already suggested that EF develops from a unitary construct to a multifactorial structure from childhood to adolescence (Brydges et al., 2014; Davidson et al., 2006; Karr et al., 2018). The raw CBS scores were converted into one weighted sum score for the youngest age group (9 - 12,99 years old), and a weighted sum score for each EF component separately (inhibition, working memory, planning and shifting) for the two older age groups (12,99 – 26 years old). These sum scores were calculated based on the model and loadings described in Laureys et al. (2022), which can be found in Supplementary Material 3. For the PCDEQ again results from previous research showed a different factor structure for young and older athletes (Laureys, Collins, et al., 2021). Standardized factor scores of the PCDEQ-C were mathematically rescaled into a score on 10 for the five factors, based upon 51 items, for participants the youngest age group. For the two older age groups, 87 items were used to make seven standardizes factor scores of the PCDEQ-2 (Hill et al., 2019), which were again rescaled into a score on 10, to make interpretation easier.

Since the EF and PCDEQ factors were computed differently for the youngest age group (aspiring stage) compared to the two older age groups (junior and senior stage), analyses were split up. First, within the youngest age group, age- and sex-related differences between gymnasts and the quasi-control group on both EF and PCDEQ factors were examined. Therefore, a 4 (age category) x 2 (sex) x 2 (group: gymnasts vs. quasi-control) ANOVA for EF and a 4 (age category) x 2 (sex) x 2 (group: gymnasts vs. quasi-control) MANOVA for the 5 PCDEQ factors was used. In the older two age groups, we first ran Pearson correlations between age and the EF and PCDEQ factors to examine whether age should be included as a covariate in further analyses. Next, a 2 (developmental stage) x 2 (sex) x 2 (group: gymnast vs. quasi-control) MANOVA for both the 4 EF and 7 PCDEQ factors was used. Significant interaction and main effects were further examined with Bonferroni post hoc tests. Values of $p \leq 0.05$ were considered statistically significant for all analyses, and were interpreted together with effect sizes. These effect sizes were calculated as partial eta squared (partial η^2); η_p^2 sizes between 0.06 and 0.14 are considered average effect, sizes above 0.14 are considered a large effect (Bennett & Allen, 2012). All data were analysed using SPSS version 26.

For the second part of this study, we focused on inter- and intrapersonal EF and PCDE differences, where we wanted to inspect to what extent gymnasts conform to a desired profile in a descriptive way. For EF, the desired profile implies that gymnasts should strive for a high score on all four components. For PCDE, a desired profile of a strong psycho-behavioural skill-set as assayed by the PCDE questionnaire (Hill et al., 2019), is put forward, which is based upon research by Collins et al. (2022). This profile strives for a maximal score on four factors (Imagery and Active Preparation, Self-Directed Control and Management, Seeking and Using Social Support and Active Coping), a medium score for 1 factor (Perfectionistic Tendencies) and a low score for 2 factors (Adverse Response to Failure and Clinical Indicators). The EF and PCDEQ profiles of four elite senior gymnasts were compared against the desired profile, against each other, and against the mean score of the quasi-control group of the same age.

To this end, we used the group of male and female senior high-level gymnasts (Age_{male} = 20.79 ± 2.86; Age_{female} = 17.40 ± 1.63). All 25 gymnasts were striving to participate at major international competitions, with the goal to get selected for finals and even win medals. So far, these gymnasts had already gathered 21 individual finals with 4 medals at the European Championships, 10 individual finals with 3 medals at the World Championships and 4 individual finals and 1 medal at the Olympic Games. Within this group of high-level gymnasts, four gymnasts (2 male, 2 female) were randomly selected to ensure anonymity, and their EF and PCDE profile was investigated in greater detail. The profiles of these gymnasts were compared with the quasi-control group of the same age (N =25). To allow for a descriptive comparison, the four individual weighted EF sum scores and the seven individual standardized PCDEQ scores were plotted on two radar charts.

Results

Between group differences

A. Youngest age group

Within the youngest age group, a significant interaction with an average effect size between age and group emerged ($F_{(3;153)}$ = 2.963; p = 0.034; η_p^2 = 0.055) for EF. In addition, there was a significant main effect for age, again with an average effect size ($F_{(3;153)}$ = 6.113; p = 0.001; η_p^2 = 0.107). At 9 years old the gymnasts scored higher than the quasi-control group, although the quasi-control group scored higher at 10 years old. At both 11 and 12 years old, the gymnasts again outperform the quasi-control group (see Table 4). No other significant main or interaction effects were found, and all other effect sizes were considered low.

A MANOVA was used to examine differences on the five PCDEQ factors. No significant multivariate interaction effects were found. A tendency towards a multivariate main effect of age groups was found ($F_{(15;436)}$ = 1.697; p = 0.052; η_p^2 = 0.050). The univariate analysis showed that factor 5 (seeking and using social support) was significantly greater in the older age group ($F_{(3;162)}$ = 3.579; p = 0.015; η_p^2 = 0.062). A significant multivariate effect emerged for sex ($F_{(5;158)}$ = 3.484; p = 0.005; η_p^2 = 0.099) and group ($F_{(5;158)}$ = 2.626; p = 0.026; η_p^2 = 0.077). Factor 4 (performance worries) was significantly higher for females (5.70 ± 0.16) compared to males (5.00 ± 0.21) and on factor 2 (imagery and active preparation) gymnasts scored higher than the quasi-control group (6.50 ± 1.6 and 5.93 ± 0.15; respectively). All effect sizes for these significant results are considered average. See Table 4 for an overview of all results.

- *Insert Table 4 here* -

B. Older age groups

Within the older age groups, Pearson correlations showed no significant relationship between age and the four EF components. For the PCDEQ factors, only one significant correlation was found between age and factor 6 (Active Coping), although the association was weak (r = 0.212). Therefore, age was not included as a covariate in the following analyses (see Table 5).

- *Insert Table 5 here* -

Secondly, the MANOVA showed a significant multivariate interaction between sex and group ($F_{(4;81)}$ = 4.502 ; p = 0.034; η_p^2 = 0.182) and a main effect for group ($F_{(4;81)}$ = 2.630 ; p = 0.040; η_p^2 = 0.115) for EF performance. Univariate analyses revealed that this interaction effect was significant for inhibition ($F_{(1;84)}$ = 10.961; p = 0.001; η_p^2 = 0.115) and planning ($F_{(1;84)}$ = 9.721; p = 0.002; η_p^2 = 0.104), both with average effect sizes. For both inhibition and planning, the male quasi-control participants had lower scores than the male gymnasts. The opposite was observed for the female participants, however, where the quasi-control group scored higher than the gymnasts. For shifting and working memory no significant interaction effects emerged.

Lastly, the MANOVA for the PCDEQ factors was examined. No significant multivariate interaction effect emerged, but there was a significant main effect for sex ($F_{(7;78)} = 6.517$; $p < 0.001$; $\eta_p^2 = 0.369$) and group ($F_{(7;78)} = 4.182$; $p = 0.001$; $\eta_p^2 = 0.273$), both with large effect sizes. Females scored higher on factor 1 (Adverse Response to Failure; 5.89 ± 0.23 for females and 4.79 ± 0.23 for males) and factor 7 (Clinical Indicators; 4.80 ± 0.20 for females and 4.07 ± 0.20 for males), and males scored higher on factor 6 (Active Coping; 6.77 ± 0.14 for males and 6.28 ± 0.14 for females). Gymnasts outperformed the control group both on factor 2 (Imagery and Active Preparation; 6.98 ± 0.19 and 6.08 ± 0.19 respectively) and factor 3 (Self-Directed Control and Management; 6.94 ± 0.15 and 6.30 ± 0.15 respectively). All results are shown in Table 6.

- *Insert Table 6 here* -

Person-centred approach

Descriptive comparisons were used to focus on the inter- and intrapersonal differences, profiles of male and female senior high-level gymnasts, by visualising the gymnasts profile against participants from the quasi-control group with the same age. The factor scores of all four EF components were all set to the same scale, to improve the interpretation of the graph.

Inspecting inter-individual differences between the four gymnasts (Figure 1), it is seen that Senior 3 scored strikingly lower on planning and working memory relative to not only the other three gymnasts, but also the quasi-control group. Senior 2 seemed to have an average to good score on all four EF components compared to both the gymnasts and the quasi-control group. Intra-personal differences between components were also visible. Senior 4, for example, has average scores for inhibition, working memory and shifting, but scored the highest on planning. The same can be said for Senior 1, who has the highest score for shifting compared to both the other three gymnasts and the quasi-control group.

- *Insert Figure 1 here* -

Exploring the PCDEQ profile revealed more variation within and between individuals (Figure 2) than on the EF components. In general, the gymnasts scored higher than the quasi-control group on factor 2 (Imagery and Active Preparation) and 3 (Self-Directed Control and Management), as was expected, and conformed better to the 'desired profile' than the quasi-control group. However, inter-personal differences between the four gymnasts are seen. Senior 2 stands out with a profile most conforming to the 'desired profile'. On the contrary, Senior 1 almost has the opposite profile, with especially less conforming scores on factor 2 (Imagery and Active Preparation) and 3 (Self-Directed Control and Management). Again, when zooming in on individual profiles, intrapersonal variation in factors is observed. Senior 3 for example, conformed highly to the desired profile on factor 1 (Adverse Response to Failure), 2 (Imagery and Active Preparation) and 6 (Active Coping), but deviated from this profile on other positive PCDEQ factors, such as factor 3 (Self-Directed Control and Management) and 5 (Seeking and Using Social Support).

- *Insert Figure 2 here* -

Discussion

The main goal of the current study was to explore EF and PCDE profiles of male and female artistic gymnasts at both childhood and adolescent ages. In the first part of this study, differences between a gymnastics group and a quasi-control group were examined. In the youngest age group, gymnasts indeed scored better on EF. The older age groups showed a specialisation in EF, with gymnasts having higher scores on inhibition than the quasi-control group. Overall, EF generally improved with increasing age, a finding that was not replicated in the older age groups. Scores for several PCDEQ factors were in favour of the gymnasts compared to the quasi-control group in both the younger and older age groups. Secondly, a person-centred approach was used to descriptively explore inter- and intra-individual differences between four senior high-level gymnast and an age-matched quasi-control group. This analysis showed a relatively closely aligned profile between all four gymnasts and the quasi-control group for the EF components, but inter-and intra-variation was observed. These inter-and intra-personal differences were even more pronounced for the PCDE-profiles.

In agreement with a large body of EF literature, this study found that both in gymnasts and the quasi-control group EF performance improves with age, at least in the years before puberty. Once puberty started, however, no differences between the middle and oldest age group emerged on the four EF components, which was also reflected in the mean scores per age group, suggesting adult levels of EF performance were reached during adolescence (Anderson et al., 2001; Huizinga et al., 2006; Laureys et al., 2022).

Research investigating EF profiles in a childhood context is very limited and mostly from a team-player-perspective. However, these studies do suggest a benefit for athletes on EF, compared to non-athletes (Formenti et al., 2021). As hypothesised, the youngest group of gymnasts already outperformed the quasi-control group in the current study, suggesting the importance of EF in sports from (late) childhood already (De Waelle et al., 2021; Formenti et al., 2021). In adolescence, when EF can be split into four (specialised) components, the role inhibition could play as a performance indicator in self-paced sports (e.g., gymnastics) became apparent again (Jacobson et al., 2014). Surprisingly, this result only applies to male gymnasts. In fact, female gymnasts performed worse than the quasi-control group on inhibition. More research is necessary to investigate this mixed sex result. It is important to point out that the effect sizes of the differences between gymnasts and the quasi-control group were only small to average (Bennett & Allen, 2012). This is however not surprising, since, in comparison with team-sports, or strategic and interceptive sports, EF are probably less determinant for (adult) performance successes in self-paced sports such as gymnastics (Krenn et al., 2018). Nevertheless, the differences found here suggest the importance of inhibition and planning specifically at the junior and senior developmental stage in self-paced sports.

A PCDEQ gymnast-specific performance profile also became apparent in both the younger and older age groups. One PCDEQ factor that the gymnasts were outstanding in from very young ages, was Imagery and Active Preparation. This is perhaps not surprising, since imagery skills have been identified as an important performance characteristic to possess and deploy in gymnastics in order to achieve great performance (Munroe-Chandler et al., 2007; Simonsmeier & Frank, 2016). Early specialisation sports further consists of athletes who are more likely to 'self-deploy' psychological characteristics around puberty ages already, because they also hit developmental challenges at an earlier age than their late-specialisation (often team-sports) athletic peers (MacNamara & Collins, 2013). However, although significant differences on two PCDEQ factors were noticed, the difference in practice between the gymnastics and quasi-control group remains relatively low (e.g., a max of a 1-point difference on a 7-point Likert scale). More research is necessary to investigate how the profile develops over time and if the PCDEQ profile found here can be generalised to other early-specialisation sports.

In contrast to what was hypothesised, there was no increase in PCDEQ factor scores with increasing age in the younger age group, nor in increasing stage in the older age group. A potential reason for the absence of age-related differences, could be that psychological skills need to be explicitly taught and practised (Dohme et al., 2017) before psycho-behavioural changes are observed. Another more likely reason is the type of assessment used here, which is a self-report and self-perception questionnaire. This type of assessment can increase the risk of self-report bias and socially desirable answers (Hill et al., 2019). Furthermore, in this specific high-level performance context, impression management strategies (i.e., trying to control the way people –athletes in this context- are perceived by others; Goffman, 2002) should also be taken into account. Nevertheless, research has indicated that athletes with superior psychological characteristics will benefit from this during their TD pathway, as this will further facilitate their athletic progression (Hill et al., 2019; MacNamara & Collins, 2015).

In both EF and PCDEQ factors and at all ages, sex differences were found. Reverse sex differences for the male and female gymnasts compared to quasi-control group were observed for inhibition, although it is unclear why these were found. Probably, next to the influence of sex in itself, this result is a combination of social, maturational and/or psychometric factors (Grissom & Reyes, 2019; Karr et al., 2018). The sex differences in the PCDEQ factors are more in line with what is generally known in psychological literature. Females scored higher on the negative psychological traits, such as Performance Worries in the youngest age group and Adverse Response to Failure or Clinical Indicators in the older age groups. Males on the other hand scored higher on the positive trait Active Coping in the oldest age group. Females generally score higher on factors related more to stress outcomes and negative feelings, especially during puberty (Mantilla et al., 2014; Ostberg et al., 2015). This puts female gymnasts more at-risk of developing negative PCDE from young ages onwards, which could hamper their TD pathway.

A second important part of this study, was to examine the EF and PCDE performance with a person-centred approach. When focusing on the individual profiles, the radar charts of especially the PCDE seem to indicate great inter-personal differences. Since all gymnasts reached the senior level and achieved great (international) performances, the intra-personal differences could suggest that a minimal threshold equal to the level of the quasi-control is necessary yet sufficient to achieve the highest level in gymnastics. Once this threshold is reached, there is no need to try to maximise every skill, but rather to leave room for individual deviation from the desired profile. This is especially true for the psycho-behavioural skills, since these are more likely to be influenced by cultural, social and contextual factors and/or challenges (Dohme et al., 2017).

The findings of this descriptive investigation are in agreement with the compensation theory already demonstrated on other dimensions of athletic performance, assuming that athletes can compensate for relative weaknesses in one area with strengths in others, once a threshold is reached (Ceci et al., 2003; MacNamara & Collins, 2013; Vaeyens et al., 2008). The results call for the need for an athlete-centred approach to develop EF and PCDE within their TD pathway, as it is clear from these findings that a one-size-fits-all approach actually does not fit all. When working with gymnasts in a TD program, we recommend coaches, sport-psychologist and other practitioners to map the cognitive and psycho-behavioural skills from early ages onwards, and individually monitor them longitudinally. This makes it possible to identify the cognitive and psycho-behavioural profile of the gymnast, and can expose issues gymnasts are struggling with, shortcomings that require attention, and monitoring of the athletes progression towards an individualized ideal profile.

This study is one of the first to extend the variable-centred approach with a person-centred approach on the same research question. However, more research is necessary to combine both approaches and gain more knowledge on EF and PCDE in athletes from a young age onwards. One way is by using a mixed methods approach of both quantitative and qualitative research in one study, or to use longitudinal follow-up to further statistically examine the person-centred approach. As is indicated, the link between improving EF and/or PCDE and the actual performance should be further investigated. Furthermore, the majority of the gymnasts in this study participated while going through their puberty. Other studies have pointed out that early or late biological maturity may have a negative effect on EF and psychological development (Chaku & Hoyt, 2019; Ge & Natsuaki, 2009; Laureys, Middelbos, et al., 2021). It is important to further investigate the frame of reference the gymnasts are using when they evaluate their own set of PCDE, since this could influence how they perceive their own psycho-behavioural skills. Therefore, the PCDEQ should rather be used as formative assessment tools, as part of a triangulation process or in combination with other methodologies to provide a more holistic athletic profile.

In conclusion, this study focused on EF and PCDE performance during TD in high-level male and female gymnastics at different developmental stages. The variable-centred approach showed that certain cognitive and psycho-behavioural skills could be interpreted as performance indicators in self-paced and early-specialisation sports, from a very early age onwards. Specifically for developing female gymnasts, coaches, parents, sport-psychologists and other practitioners should be aware of the risk that female athletes are more susceptible to score high on negative psycho-behavioural skills, and perhaps use a more closely follow-up. The athlete-centred approach allowed to investigate individual variation in more detail, and seemed to indicate that once an athlete scored above a specific threshold on all variables, there is no necessity for trying to maximise each and every of these skills. Instead, there is room for individual profile variation. Since individual profiles were observed, we recommend an athlete-centred approach in all TD phases from a young age onwards. Using this approach will help the individual athlete to develop the skills and characteristics necessary for him/her specifically to overcome challenges during the TD process and perform in the best possible way at senior stage.

Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

The data that support the findings of this study are available from the corresponding author, FL, upon reasonable request.

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Supplementary Material

10.6084/m9.figshare.20109011

Tables

Table 1. Numbers of participating gymnasts per developmental stage and sex.

	Aspiring		Junior		Senior		Total
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	
9 yo	8	13					21
10 yo	18	24					42
11 yo	13	8					21
12 yo	2	3					5
13 yo				3			3
14 yo			6	8			14
15 yo			4			1	5
16 yo						5	5
17 yo					2	2	4
18 yo and older					11	4	15
Total	41	48	10	11	13	12	135

yo = years old

Table 2. Mean age and numbers per sex, group and age group

	Male		Female	
	Gymnasts	Quasi-control	Gymnasts	Quasi- control
Youngest age group	10.72 ± 0.91 (N = 41)	10.72 ± 0.90 (N = 41)	10.48 ± 0.75 (N = 48)	11.35 ± 1.19 (N = 48)
Middle age group	15.03 ± 0.58 (N = 10)	15.03 ± 0.57 (N = 10)	14.17 ± 0.45 (N = 11)	14.15 ± 0.47 (N = 11)
Oldest age group	20.79 ± 2.75 (N = 13)	17.80 ± 0.34 (N = 13)	17.40 ± 1.56 (N = 12)	17.08 ± 0.66 (N = 12)

Table 3. Psychological characteristics of developing excellence (PCDE) factors per age category.

	10-12,99 years old	13-26 years old
Factor 1	Adverse Response to Failure (-)	Adverse Response to Failure (-)
Factor 2	Imagery and Active Preparation (+)	Imagery and Active Preparation (+)
Factor 3	Self-Directed Control and Management (+)	Self-Directed Control and Management (+)
Factor 4	Performance Worries (-)	Perfectionistic Tendencies (+/-)
Factor 5	Seeking and Using Social Support (+)	Seeking and Using Social Support (+)
Factor 6		Active Coping (+)
Factor 7		Clinical Indicators (-)

+ = adaptive factor, - = maladaptive factor, +/- = dual-effect factor

Table 4. Means and standard deviations (SD) from the sum scores on each factor of the CBS and PCDEQ test batteries for the young age categories, with the F, (df), P and partial η² values of the Three-way Anova (EF) and the MANOVA (PCDE).

	9 yo mean ± SD				**10 yo mean ± SD**				**11 yo mean ± SD**				**12 yo mean ± SD**				**Age**	**Sex**	**Group**	**Age x Sex**	**Age x Group**	**Sex x Group**	**Age x Sex x Group**
	Gymnast		**Control**		**Gymnast**		**Control**		**Gymnast**		**Control**		**Gymnast**		**Control**								
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**							
EF Univariate	15.9 ± 1.64	16.5 ± 1.63	15.3 ± 2.25	15.0 ± 1.31	15.5 ± 2.21	16.4 ± 2.26	16.4 ± 1.82	17.6 ± 2.40	17.9 ± 1.87	18.1 ± 2.34	17.1 ± 1.78	17.1 ± 1.47	17.2 ± 1.39	18.0 ± 2.57	17.1 ± 0.23	17.0 ± 2.17	F = 6.113 (3;153) **p = 0.001** η² = 0.107	F = 0.992 (1;153) p = 0.321 η² = 0.006	F = 0.850 (1;153) p = 0.358 η² = 0.006	F = 0.558 (3;153) p = 0.644 η² = 0.011	F = 2.963 (3;153) **p = 0.034** η² = 0.055	F = 0.319 (1;153) p = 0.573 η² = 0.002	F = 0.179 (3;153) p = 0.911 η² = 0.003
	a, d				a, b, d				c, d				a, b, c, d										
PCDE Multivariate																	F = 1.697 (15;436.6) **p = 0.052** η² = 0.050	F = 3.484 (5;158) **p = 0.005** η² = 0.099	F = 2.626 (5;158) **p = 0.026** η² = 0.077	F = 1.367 (15;436,6) p = 0.160 η² = 0.041	F = 1.073 (15;436,6) p = 0.379 η² = 0.033	F = 1.489 (5;158) p = 0.196 η² = 0.045	F = 1.428 (15;436,6) p = 0.130 η² = 0.043
Factor 1 Adverse Response to Failure	4.7 ± 1.29	4.3 ± 1.46	4.1 ± 1.73	5.2 ± 1.32	4.5 ± 1.34	4.5 ± 1.26	4.6 ± 1.72	5.3 ± 1.44	4.2 ± 1.60	4.3 ± 2.42	4.2 ± 1.44	4.6 ± 1.73	3.9 ± 1.85	3.4 ± 1.69	3.9 ± 0.51	4.5 ± 1.47	F = 1.206 (3;162) p = 0.309 η² = 0.022	F = 0.621 (1;162) p = 0.432 η² = 0.004	F = 1.124 (1;162) p = 0.291 η² = 0.007	F = 0.044 (3;162) p = 0.988 η² = 0.001	F = 0.164 (3;162) p = 0.920 η² = 0.003	F = 2.381 (1;162) p = 0.125 η² = 0.014	F = 0.242 (3;162) p = 0.867 η² = 0.004
Factor 2 Imagery and Active Preparation	6.6 ± 0.96	6.5 ± 0.85	6.8 ± 0.85	6.1 ± 1.13	6.1 ± 1.01	6.7 ± 0.98	6.3 ± 1.25	6.0 ± 1.28	6.6 ± 1.12	6.5 ± 0.87	6.1 ± 1.57	5.7 ± 0.49	5.9 ± 0.54	7.2 ± 0.93	4.5 ± 2.90	6.0 ± 1.00	F = 0.994 (3;162) p = 0.397 η² = 0.018	F = 0.921 (1;162) p = 0.339 η² = 0.006	F = 7.032 (1;162) **p = 0.009** η² = 0.042	F = 2.463 (3;162) p = 0.064 η² = 0.044	F = 1.249 (3;162) p = 0.294 η² = 0.023	F = 1.021 (1;162) p = 0.314 η² = 0.006	F = 0.285 (3;162) p = 0.836 η² = 0.005
Factor 3 Self-Directed Control and Management	7.2 ± 0.66	7.8 ± 0.85	8.8 ± 1.02	7.5 ± 0.78	7.2 ± 1.12	8.0 ± 1.20	7.6 ± 1.52	6.6 ± 1.82	7.5 ± 1.80	8.1 ± 1.66	7.8 ± 1.21	7.6 ± 1.39	7.1 ± 0.20	8.4 ± 0.98	6.5 ± 0.98	7.9 ± 1.28	F = 1.150 (3;162) p = 0.331 η² = 0.021	F = 1.206 (1;162) p = 0.274 η² = 0.007	F = 0.236 (1;162) p = 0.628 η² = 0.001	F = 1.352 (3;162) p = 0.259 η² = 0.024	F = 1.706 (3;162) p = 0.168 η² = 0.031	F = 4.758 (1;162) p = 0.031 η² = 0.029	F = 0.678 (3;162) p = 0.567 η² = 0.012
Factor 4 Performance Worries	6.0 ± 1.59	5.6 ± 0.84	4.5 ± 1.00	6.5 ± 1.24	5.2 ± 1.03	5.7 ± 1.38	5.2 ± 1.94	6.0 ± 1.06	4.6 ± 1.29	5.7 ± 1.74	4.9 ± 0.96	5.2 ± 1.03	5.0 ± 1.77	6.1 ± 1.87	4.6 ± 1.40	4.8 ± 1.33	F = 1.221 (3;162) p = 0.304 η² = 0.022	F = 6.802 (1;162) **p = 0.010** η² = 0.040	F = 1.088 (1;162) p = 0.298 η² = 0.007	F = 0.038 (3;162) p = 0.990 η² = 0.001	F = 0.512 (3;162) p = 0.675 η² = 0.009	F = 0.220 (1;162) p = 0.640 η² = 0.001	F = 2.441 (3;162) p = 0.066 η² = 0.043
Factor 5 Seeking and Using Social Support	5.1 ± 0.72	4.9 ± 0.89	4.8 ± 1.42	4.3 ± 0.93	5.6 ± 1.03	5.1 ± 0.89	5.0 ± 1.06	6.0 ± 1.16	5.3 ± 0.99	5.4 ± 0.93	5.4 ± 1.31	5.4 ± 1.18	5.1 ± 0.13	4.6 ± 0.37	5.6 ± 0.00	5.7 ± 0.99	F = 3.579 (3;162) **p = 0.015** η² = 0.062	F = 0.136 (1;162) p = 0.712 η² = 0.001	F = 0.240 (1;162) p = 0.625 η² = 0.001	F = 0.273 (3;162) p = 0.634 η² = 0.010	F = 1.284 (3;162) p = 0.282 η² = 0.023	F = 0.925 (1;162) p = 0.337 η² = 0.006	F = 1.845 (3;162) p = 0.141 η² = 0.033

EF = Executive Function; PCDE = Psychological Characteristics of Developing Excellence. A mean is significantly different from another mean if they have other superscript letters (a. b. c. d. e. f. g.).

Table 5. Correlations between the four EF factors and age (A) and the seven PCDE factors and age (B).

A	Age	Inhibition	Planning	Shifting
Inhibition	0.047			
Planning	0.126	0.232*		
Shifting	-0.029	0.236*	0.269**	
Working Memory	0.090	0.309**	0.189	0.335**

B	Age	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Factor 1	-0.181						
Factor 2	0.116	0.160					
Factor 3	0.063	-0.224*	0.496**				
Factor 4	0.111	0.701**	0.249*	-0.164			
Factor 5	0.034	-0.280**	0.313**	0.199	-0.253*		
Factor 6	0.212*	-0.377**	0.302**	0.299**	-0.099	0.183	
Factor 7	0.049	0.632**	0.199	-0.194	0.478**	-0.363**	-0.307**

Correlation is significant at the 0.05 level (*) or 0.01 level (**).
EF = Executive Function; PCDE = Psychological Characteristics of Developing Excellence, Factor 1: Adverse Response to Failure, Factor 2: Imagery and Active Preparation, Factor 3: Self-Directed Control and Management, Factor 4: Perfectionistic Tendencies, Factor 5: Seeking and Using Social Support, Factor 6: Active Coping, Factor 7: Clinical Indicators.

Table 6. Means and standard deviations (SD) from the sum scores on each factor of the CBS and PCDEQ test batteries for the older age categories, with the F, (df), P and partial η² values of the MANCOVA (EF and PCDE).

	Middle Age Group mean ± SD				**Oldest Age Group mean ± SD**										
	Gymnast		**Control**		**Gymnast**		**Control**		**Stage**	**Sex**	**Group**	**Sex x Stage**	**Sex x Group**	**Stage x Group**	**Sex x Stage x Group**
	Male	**Female**	**Male**	**Female**	**Male**	**Female**	**Male**	**Female**							
EF Multivariate									F = 1.780 (4 ; 81) p = 0.141 η^2 = 0.081	F = 2.335 (4 ; 81) p = 0.062 η^2 = 0.103	F = 2.630 (4 ; 81) **p = 0.040** η^2 = 0.115	F = 0,545 (4 ; 81) p = 0.703 η^2 = 0.026	F = 4.502 (4 ; 81) **p = 0.002** η^2 = 0.182	F = 1.605 (4 ; 81) p = 0.181 η^2 = 0.073	F = 0,524 (4 ; 81) p = 0.718 η^2 = 0.025
Inhibition	0.6 ± 0.06	0.6 ± 0.11	0.5 ± 0.12	0.6 ± 0.10	0.6 ± 0.11	0.6 ± 0.14	0.5 ± 0.11	0.6 ± 0.12	F = 0.015 (1 ; 84) p = 0.904 η^2 < 0.001	F = 0.015 (1 ; 84) p = 0.904 η^2 < 0.001	F = 5.041 (1 ; 84) **p = 0.027** η^2 = 0.057	F < 0.001 (1 ; 84) p = 0.999 η^2 < 0.001	F = 10.961 (1 ; 84) **p = 0.001** η^2 = 0.115	F = 1.207 (1 ; 84) p = 0.275 η^2 = 0.014	F = 0.288 (1 ; 84) p = 0.593 η^2 = 0.003
Planning	3.0 ± 1.24	1.8 ± 0.57	1.9 ± 0.78	2.2 ± 0.65	2.7 ± 0.78	2.4 ± 0.64	2.1 ± 0.76	2.4 ± 1.06	F = 1.275 (1 ; 84) p = 0.262 η^2 = 0.015	F = 1.275 (1 ; 84) p = 0.262 η^2 = 0.015	F = 3.182 (1 ; 84) **p = 0.078** η^2 = 0.036	F = 1.900 (1 ; 84) p = 0.172 η^2 = 0.022	F = 9.721 (1 ; 84) **p = 0.002** η^2 = 0.104	F < 0.001 (1 ; 84) p = 0.992 η^2 < 0.001	F = 1.628 (1 ; 84) p = 0.206 η^2 = 0.019
Shifting	15.2 ± 2.15	15.1 ± 1.97	15.0 ± 1.70	16.6 ± 2.51	15.6 ± 1.39	16.5 ± 1.78	15.1 ± 0.95	17.1 ± 3.45	F = 1.928 (1 ; 84) p = 0.169 η^2 = 0.022	F = 6.067 (1 ; 84) **p = 0.016** η^2 = 0.067	F = 0.547 (1 ; 84) p = 0.462 η^2 = 0.006	F = 0.686 (1 ; 84) p = 0.410 η^2 = 0.008	F = 2.497 (1 ; 84) p = 0.118 η^2 = 0.029	F = 0.474 (1 ; 84) p = 0.493 η^2 = 0.006	F = 0.092 (1 ; 84) p = 0.762 η^2 = 0.001
Working Memory	9.9 ± 1.44	9.6 ± 0.74	9.2 ± 1.59	9.5 ± 1.83	9.9 ± 0.75	9.8 ± 1.40	10.0 ± 1.14	10.6 ± 1.57	F = 3.577 (1 ; 84) p = 0.062 η^2 = 0.041	F = 0.210 (1 ; 84) p = 0.648 η^2 = 0.002	F = 0.002 (1 ; 84) p = 0.967 η^2 < 0.001	F = 0.257 (1 ; 84) p = 0.702 η^2 = 0.002	F = 1.420 (1 ; 84) p = 0.237 η^2 = 0.017	F = 2.467 (1 ; 84) p = 0.120 η^2 = 0.029	F = 0.061 (1 ; 84) p = 0.805 η^2 = 0.001
PCDE Multivariate									F = 1.607 (7 ; 78) p = 0.146 η^2 = 0.126	F = 6.517 (7 ; 78) **p < 0.001** η^2 = 0.369	F = 4.182 (7 ; 78) **p = 0.001** η^2 = 0.273	F = 1.182 (7 ; 78) p = 0.323 η^2 = 0.096	F = 1.640 (7 ; 78) p = 0.137 η^2 = 0.128	F = 1.869 (7 ; 78) **p = 0.086** η^2 = 0.144	F = 0.282 (7 ; 78) p = 0.959 η^2 = 0.025
Factor 1 Adverse Response to Failure	4.7 ± 1.75	6.1 ± 1.00	4.9 ± 1.45	5.7 ± 1.64	4.7 ± 1.97	5.8 ± 1.43	4.8 ± 1.28	5.9 ± 1.40	F < 0.001 (1 ; 84) p = 0.988	F = 12.383 (1 ; 84) **p = 0.001**	F = 0.002 (1 ; 84) p = 0.960	F = 0.002 (1 ; 84) p = 0.965	F = 0.224 (1 ; 84) p = 0.637	F = 0.102 (1 ; 84) p = 0.750	F = 0.244 (1 ; 84) p = 0.622

									$\eta^2 < 0.001$	$\eta^2 = 0.128$	$\eta^2 < 0.001$	$\eta^2 < 0.001$	$\eta^2 = 0.003$	$\eta^2 = 0.001$	$\eta^2 = 0.003$
Factor 2	6.3	6.9	6.0	6.1	7.2	7.4	6.0	6.3	F = 1.987	F = 1.374	F = 11.184	F = 0.003	F = 0.181	F = 1.105	F = 0.380
Imagery and	± 1.63	± 0.96	± 1.69	± 0.49	± 1.06	± 1.50	± 1.44	± 1.03	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)
Active Preparation									$p = 0.162$	$p = 0.245$	**$p = 0.001$**	$p = 0.955$	$p = 0.672$	$p = 0.296$	$p = 0.539$
									$\eta^2 = 0.023$	$\eta^2 = 0.016$	$\eta^2 = 0.118$	$\eta^2 < 0.001$	$\eta^2 = 0.002$	$\eta^2 = 0.013$	$\eta^2 = 0.005$
Factor 3	7.2	6.9	6.3	6.0	6.8	6.8	6.2	6.6	F = 0.008	F = 0.149	F = 9.663	F = 1.379	F = 0.182	F = 1.002	F = 0.116
Self-Directed	± 1.10	± 0.47	± 0.92	± 0.81	± 1.02	± 1.18	± 1.18	± 0.97	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)
Control									$p = 0.930$	$p = 0.701$	**$p = 0.003$**	$p = 0.244$	$p = 0.671$	$p = 0.320$	$p = 0.735$
and Management									$\eta^2 < 0.001$	$\eta^2 = 0.002$	$\eta^2 = 0.103$	$\eta^2 = 0.016$	$\eta^2 = 0.002$	$\eta^2 = 0.012$	$\eta^2 = 0.001$
Factor 4	4.9	5.1	5.9	5.4	5.7	5.7	5.6	5.7	F = 1.645	F = 0.044	F = 1.509	F = 0.150	F = 0.285	F = 1.977	F = 0.588
Perfectionistic	± 1.37	± 0.82	± 1.10	± 1.13	± 1.50	± 1.09	± 1.13	± 1.25	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)
Tendencies									$p = 0.203$	$p = 0.834$	$p = 0.223$	$p = 0.699$	$p = 0.595$	$p = 0.163$	$p = 0.445$
									$\eta^2 = 0.019$	$\eta^2 = 0.001$	$\eta^2 = 0.018$	$\eta^2 = 0.002$	$\eta^2 = 0.003$	$\eta^2 = 0.023$	$\eta^2 = 0.007$
Factor 5	6.7	7.2	7.0	7.3	7.1	7.7	7.3	7.3	F = 1.702	F = 2.636	F = 0.195	F = 0.045	F = 0.730	F = 0.243	F = 0.184
Seeking and Using	± 1.14	± 0.87	± 1.01	± 1.13	± 1.20	± 1.34	± 1.14	± 0.88	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)
Social Support									$p = 0.196$	$p = 0.128$	$p = 0.223$	$p = 0.832$	$p = 0.395$	$p = 0.623$	$p = 0.669$
									$\eta^2 = 0.020$	$\eta^2 = 0.027$	$\eta^2 = 0.018$	$\eta^2 < 0.001$	$\eta^2 = 0.009$	$\eta^2 = 0.003$	$\eta^2 = 0.002$
Factor 6	7.0	5.6	6.6	6.4	7.1	6.6	6.4	6.5	F = 1.752	F = 6.15	F = 0.454	F = 1.805	F = 4.980	F = 2.663	F = 0.611
Active Coping	± 0.87	± 0.56	± 0.94	± 0.96	± 1.11	± 0.80	± 1.09	± 0.92	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)
									$p = 0.189$	**$p = 0.015$**	$p = 0.502$	$p = 0.183$	**$p = 0.028$**	$p = 0.106$	$p = 0.436$
									$\eta^2 = 0.020$	$\eta^2 = 0.068$	$\eta^2 = 0.005$	$\eta^2 = 0.021$	$\eta^2 = 0.056$	$\eta^2 = 0.031$	$\eta^2 = 0.007$
Factor 7	3.9	4.4	4.1	4.6	4.4	5.0	3.8	5.2	F = 1.297	F = 6.558	F = 0.001	F = 0.773	F = 0.571	F = 0.539	F = 0.575
Clinical Indicators	± 1.42	± 1.01	± 1.48	± 1.24	± 1.52	± 0.86	± 1.42	± 1.77	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)	(1 ; 84)
									$p = 0.258$	**$p = 0.012$**	$p = 0.977$	$p = 0.382$	$p = 0.452$	$p = 0.465$	$p = 0.450$
									$\eta^2 = 0.015$	$\eta^2 = 0.072$	$\eta^2 < 0.001$	$\eta^2 = 0.009$	$\eta^2 = 0.007$	$\eta^2 = 0.006$	$\eta^2 = 0.007$

EF = Executive Function; PCDE = Psychological Characteristics of Developing Excellence.

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Figure captions

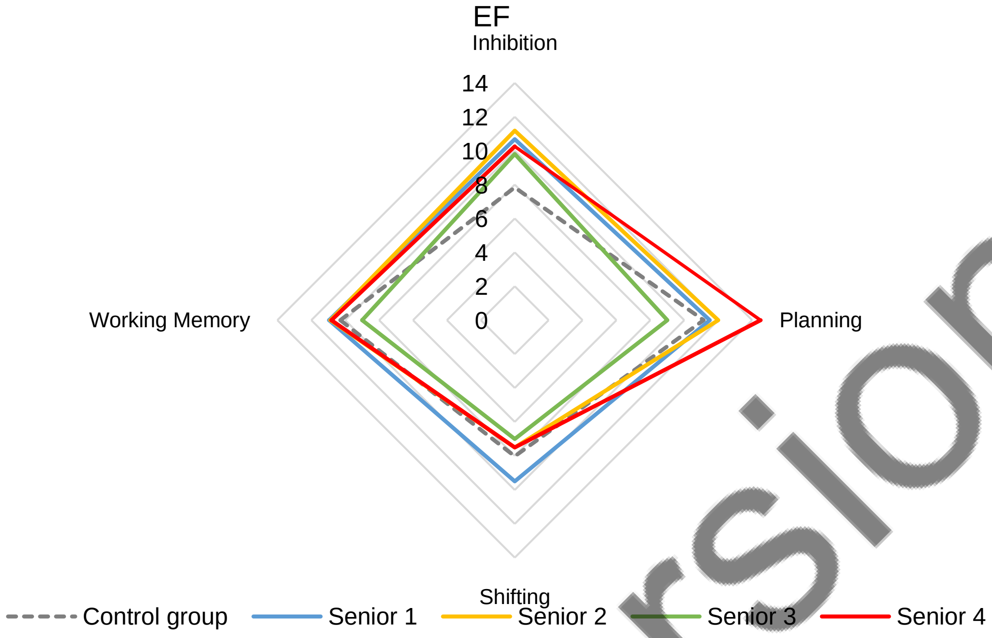

Figure 1. Radar plots from the four EF components for the four senior high-level gymnast and a quasi-control group with the same age.

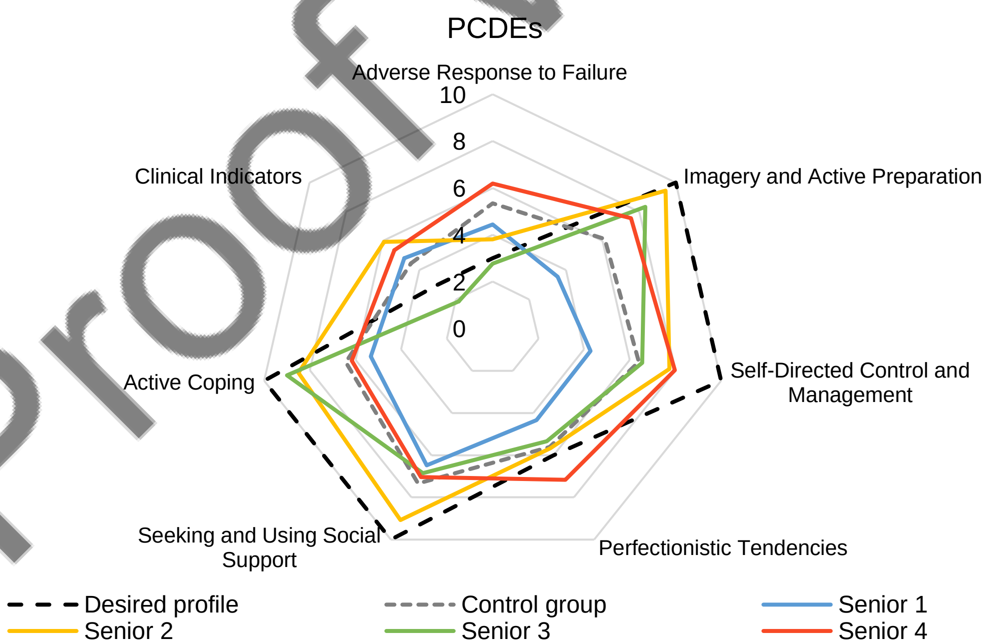

Figure 2. Radar plots from the 7 PCDE factors for the four senior high-level gymnast and a quasi-control group with the same age. A desired profile is also portrayed on this graph, based Collins et al. (2022).

Supplementary Material 1

Table A. Numbers of participating quasi-controls per sport and sex.

	Male	Female	Total
Judo	3		3
Jujitsu		1	1
Karate	1	1	2
Kickboxing		3	3
Athletics	6	5	11
Triathlon		1	1
Swimming		6	6
Rowing		2	2
Fitness	3		3
Fencing	2		2
Horseback riding		8	8
Deep-free diving		1	1
Badminton		1	1
Squash	1		1
Table tennis		1	1
Padel		1	1
Frisbee	1	1	2
Handball	1		1
Football	35	4	39
Volleyball	3	15	18
Basketball	4	4	8
Korfball	4	4	8
Hockey		12	12
Total	64	71	135

Supplementary Material 2

A detailed overview of the seven CBS tests, used in this study, with the outcome measures where the weighted sum scores for each EF components is based on, and a screenshot of each test (Figure A). Test-retest reliability scores per test were added (Hampshire et al., 2012; Robertson et al., 1997).

Spatial Span (SS) is a task based on the Corsi Block Tapping Task (Corsi, 1972) and measures a persons' ability to remember the relations between objects in space (r = 0.62). This test consists of a grid of 4x4 boxes, that will light up in a random order on the screen. Participants were instructed to tap the boxes in the same sequence as they previously appeared on the screen. The first trial always had a span length of four blocks. When a trial was executed correctly (correct locations in the correct order) the next trial contained one extra box. An incorrect trial was followed with a trial containing one box less. The test ended after three incorrect responses. Response accuracy (SS RA) was used as performance indicator for the spatial span task, and was calculated as the maximum number of blocks remembered correctly for each participant.

Double Trouble (DT) is an adaption of the Stroop test and mainly assesses inhibitory control (Stroop, 1992). Three words are presented to the participant and participants were asked to indicate which of two coloured words at the bottom described the colour of the word at the top (r = 0.92). The test lasted 90 seconds in which participants had to give as many correct responses as possible. For this test, three performance indicators were selected. First, total response accuracy (DT RA) was calculated as percentage of correct trials for each participant. Second, mean response time (i.e. the time between the words appearing on screen and the participants tapping on a word) on double incongruent trials (DT RT II) was calculated for each participant. Double incongruent trials were trials where the top word and target word were different and had a different colour. Third, mean response time on double congruent trials (DT RT CC) was calculated for each participant. Double congruent trials were trials where both top word and target word were the same and had the same colour.

Token Search (TS) is a self-guided search task that mainly assesses spatial working memory (Collins et al., 1998). Participants were presented with a number of boxes randomly placed on the screen and were asked to find a token that was hidden underneath the boxes (r = 0.66). Each box contained the token only once and the next hiding place was unpredictable. The task requires to hold the selected boxes in memory. Selection of an empty box twice or a box that had previously held the token, resulted in a failure. When a trial was executed correctly (all tokens found without error) the next trial contained one extra box. After an incorrect trial the next trial contained one box less. The test ended after three incorrect responses. Response accuracy (TS RA) was selected as performance indicator for the token search task and was calculated as the maximum number of boxes found without error for each participant.

Odd One Out (OO) is a modern adaptation of classical tests of fluid intelligence (Brenkel et al., 2017), and mainly assesses deductive reasoning and shifting. This task consists of nine sets of shapes that differ from each other in colour, shape and size (r =

0.73). The participant had to point out which shape was the most different from the others. A correct response resulted in the next trial being more complex, while an incorrect trial would result in the next trial being less complex. The grade of complexity depended on the amount of variance on the three levels (colour, shape, size) within the nine figures. The test lasted 180 seconds in which participants had to give as many correct responses as possible. Response accuracy as well as response time were selected as performance indicators for this task. Response accuracy for the odd one out task (OO RA) was calculated as the number of correct attempts for each participant (*N attempts – N errors*). For response time (i.e. time between the trial appearing on screen and the participants tapping on a shape), the mean response time per trial was calculated for each participant (OO RT).

Spatial Planning (SP) is an adapted version of the Tower of London Task (Shallice, 1982), which is primarily used to assess planning ability. Participants were asked to sort balls that are positioned on a tree-shaped frame in numerical order in as few moves as possible, by replacing one ball per move (r = 0.87). The problems became progressively more complex to solve as the participant progressed through the task. The test lasted 180 seconds in which participants had to solve as many problems as possible. Response accuracy was used as a performance indicator for this task and was calculated in two steps. First, trial scores were calculated per trial using the following formula: (*minimum moves required * 2) – moves made*. The total response accuracy (SP RA) was then calculated as the sum of all trial scores for each participant.

Monkey Ladder (ML) is based on a task from the non-human primate literature (Inoue & Matsuzawa, 2007) and mainly assesses visuospatial working memory, or the ability to hold information in memory and to manipulate or update it depending of the purpose or the circumstances. Participants were presented with a number of boxes randomly placed on the screen, with each box containing a number ranging from 1 to the number of boxes (r = 0.57). Participants were asked to memorize the numbers appearing in each box and to tap the boxes in numerical order as soon as the numbers disappeared. When a trial was executed correctly, the next trial contained one extra box. After an incorrect trial the next trial contained one box less. The test ended after three incorrect responses. Response accuracy (ML RA) was selected as performance indicator for the monkey task and was calculated as the maximum number of boxes remembered correctly for each participant.

Sustained Attention to Response Task (SART, (Robertson et al., 1997) mainly assesses inhibition. Participants were presented with single digits in the centre of the screen, each digit appeared for 250 ms (r = 0.76). Participants were asked to respond with a tap on the “GO” button on the screen to each digit (GO) as quickly as possible. However, when the digit “3” appeared on screen (NO GO), participants were asked to withhold a response. Participants had to maintain their attention to this task for four minutes. The response accuracy score (SART RA NG) was calculated as the percentage of correct NO GO trials for each participant.

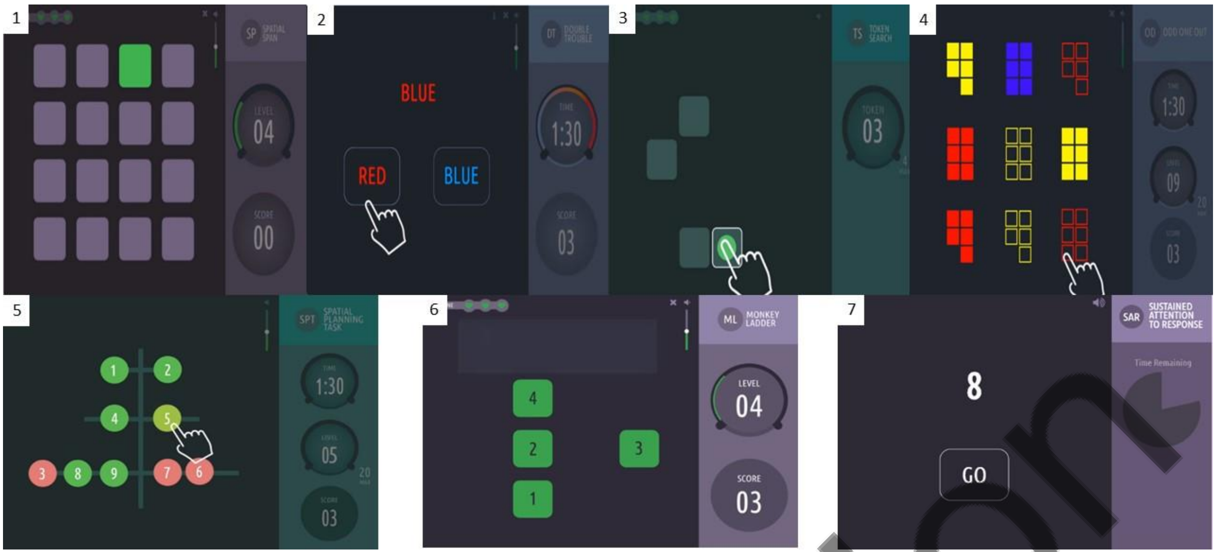

Figure A. Screenshot of the seven CBS tests. 1) Spatial Span, 2) Double Trouble, 3) Token Search, 4) Odd One Out, 5) Spatial Planning, 6) Monkey Ladder, 7) Sustained Attention to Response (SART)

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Supplementary Material 3

This appendix provides additional detail on the model upon which the weighted sum scores for the four executive functions were based, as well as how this weighted sum scores were calculated. In a recent study (Laureys et al., 2022), a confirmatory factor analyses using the same seven tests from this study was performed on a sample of 818 children between 12 and 17.99 years old. The results demonstrated that a four-factor model provided the best fit for this age group with these seven tests (Figure B).

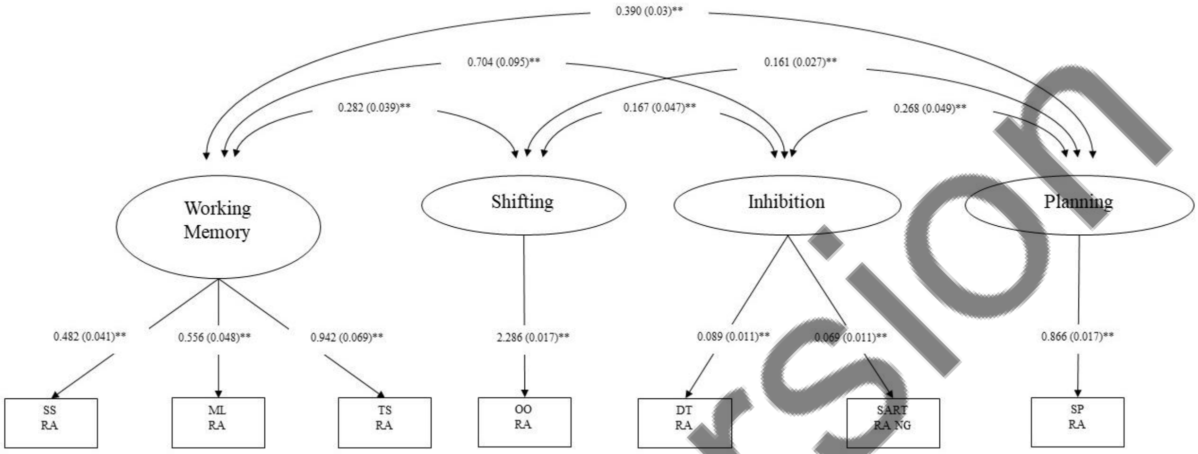

Figure B. Factor structure for the adolescent group. Estimates (standard errors) are displayed (**p < 0.001, * p < 0.05), error variances and residuals are not displayed. SS RA = Spatial Span Response Accuracy; ML RA = Monkey Ladder Response Accuracy; TS RA = Token Search Response Accuracy; OO RA = Odd One Out Response Accuracy; DT RA = Double Trouble Response Accuracy; SART RA NG = Sustained Attention To Response Task Response Accuracy No Go; SP RA = Spatial Planning Response Accuracy. (from Laureys et al., submitted for publication)

This four-factor model also includes standardized loadings for each test to evaluate the relative contribution of each test towards the four EF components, while taking into account the other tests. While the sample in the study of Laureys and colleagues was quite large, and hence allowed this kind of elaborate factor analysis, the sample of the current study was not large enough to do so. Since the sample of the study and Laureys and colleagues (Laureys et al., 2022) is representative for the Flemish youth, and thus the sample of the current study, factor loadings from the study of Laureys and colleagues could be used to calculate a weighted sum score for the four EF components, which best approaches the factor scores that would have been obtained within the original model. Hence, each individual test score was multiplied by their respective standardized factor loading for each EF factor, and then the sum of these weighted scores was calculated. Table A provides an overview of the calculated weighted sum scores with the standardized factor loading for each test.

Table B. Overview of the calculation of the weighted sum scores with the standardized factor loadings for each test.

Inhibition	= 0.572*DTRA + 0.266*SARTRANG
Planning	= SPRA
Shifting	= OORA
Working Memory	= 0.441*MLRA + 0.457*SSRA + 0.518*TSRA

DTRA: Double Trouble Response Accuracy; SARTRANG: Sustained Attention to Response Response Accuracy No Go condition; SPRA: Spatial Planning Response Accuracy; OORA: Odd One Out Response Accuracy; MLRA: Monkey Ladder

Response Accuracy; SSRA: Spatial Span Response Accuracy; TSRA: Token Search Response Accuracy

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